The final cost is that of the SCMS itself, which will ensure that vehicles will be able to distinguish trustworthy message sources from those that are not, and, thereby, ensure that the V2V system operates most effectively. We anticipate that the initial and ongoing cost of this SCMS can be covered with a one-time fee of $3.14 per new vehicle sold. In other words, supporting the functions of the SCMS would add an additional $3.14 to the cost of each vehicle sold.

In summary, supporting the functions of the SCMS and communications would add an estimated additional $11.44 to $12.64 to the average cost of each vehicle sold.

Table XI-1 Summary of Preliminary Costs per Vehicle

Cost category	Amount in dollars
Vehicle Equipment Costs	$329 in 2020, decreasing to $186 to $199 in 2058
Fuel Economy Impact	$9 - $18
Security Credentials Costs	$3.14
Communications Costs	$8.30 - $8.50
Total Costs	$341 to $350 in 2020, decreasing to $209 - $227 in 2058

C. Projected vehicle equipment costs

To fully evaluate the vehicle equipment costs, we first estimate the costs for the following potential system configurations.

- Original Equipment Manufacturer:
    - Full V2V system installed in new passenger vehicles (passenger cars and light trucks)
- Aftermarket:
    - Retrofit: connects to the vehicle's data bus, sends and receives BSM, and provides advisories/warnings
    - Self-contained: does not connect to the vehicle's data bus and only uses a wire to get power from the vehicle, sends and receives BSM, and provides advisories/warnings
    - Vehicle Awareness Device: uses a wire to get power from the vehicle, sends out but does not receive BSM, and does not provides advisories/warnings

Second, we consider three technology sales scenarios that represent potential rates at which these V2V systems can be adopted into the vehicle fleet. Finally, we apply our knowledge of learning (the potential savings that manufacturers can realize due to their experience producing the equipment), based on the three sales scenarios, to show what potential final equipment costs can be.

1. OEM devices

For V2V systems installed on vehicles as original equipment, our preliminary estimates are based on confidential information provided by two suppliers. Relying on that information, NHTSA estimates that the cost to install the supplier equipment into the vehicle will result in a per-vehicle cost to the consumer of $342.80 ($327.13 + $15.67) in 2012 dollars. As shown in Table XI-2, below, we anticipate that the equipment at the supplier level will cost $216.79, while the installation will cost $10.38. After accounting for the retail price equivalent of 1.51, which includes the additional costs necessary before the product reaches the consumer, and also for the reduction in costs due to the current installation rate of GPS units (meaning that if GPS is already present on a vehicle, the addition of V2V technology does not require another GPS unit), we estimate the increase in per-vehicle cost will be $329.14 in 2020. We further explain our estimates for the supplier costs, installation costs, and GPS market penetration in separate sections below.

We anticipate that manufacturers and suppliers will realize cost savings over time due to additional experience in manufacturing V2V safety equipment; however, any potential cost savings due to this additional experience are not included in cost tables until after these effects are discussed in the section titled "Learning," below.

Table XI-2 Summary of Likely Costs in Year 1 for New Vehicles (2012 dollars)

	Variable Costs[311]	Consumer Costs[312]
Supplier Costs	$216.79	$327.13
Installation Costs	$10.38	$15.67
Minus Current GPS Installation	$9.20	$13.89
Total	$217.97	$329.14

a) Variable costs to OEMs

As shown in the "Total" row in Table XI-3, below, our current preliminary estimate is that the V2V equipment that suppliers provide to OEMs will cost $216.79.

As discussed in Section V.B.2, we assume that two DSRC radios and two DSRC antennas are necessary: One DSRC to send and receive the BSM, and a second to handle security aspects of receiving certificates, the certificate revocation list, etc. The supplier cost estimate of $130 for 2 DSRC transmitters and receivers is composed of $70 for the first DSRC and $60 for the second. The $10 reduction in cost for the second DSRC was based upon the assumption that

[311] "Variable costs," in the table, refer to the direct cost – that is, the cost of the parts and materials – to the manufacturer to include this technology in a vehicle.
[312] "Consumer costs" refer to the variable costs plus the fixed costs that the manufacturer incurs and passes forward to the consumer.

the two DSRCs would be packaged together, thereby resulting in lower labor in assembling this combined package at the supplier, as well as lower parts costs to package them together rather than individually. No such assumption was made for the antenna, since these have to remain physically separate in order to avoid interfering with each other.

Table XI-3 Likely Supplier Costs to OEM

Component	Weight[313]	Cost
	(in lb.)	(2012 dollars)
DSRC Transmitter/Receiver (2)	0.65	130
DSRC Antenna (2)	0.44	10
Electronic Control Unit	0.55	45
GPS		14
GPS Antenna	0.22	4
Wiring	1.20	9
Displays	0.17	4.79
Total	3.23	216.79

Our information on the variable costs to OEMs, when they are purchasing supplies, is based on data received from two suppliers in response to a voluntary request for cost information sent to eight suppliers of V2V equipment. In order to help ensure consistent production estimates, we asked the suppliers to prepare their cost estimates based upon the assumption of high-volume production (i.e., meaning at least 250,000 sales per make/model), in order to model the expected production that would result if, sometime in the future, the agency required V2V and if all light vehicle sales were thus affected. This assumption helped ensure consistent estimates across suppliers who responded, since low volume sales result in very high initial prices, and if each responding supplier had picked a different volume of sales, the responses would not have been easily comparable. Again, assumptions regarding the learning curve will be applied later in the analysis.

We made several adjustments to the information we received from the two suppliers to arrive at the above estimates. First, the agency has changed some of its assumptions since requesting information from these suppliers (e.g., we now believe that two DSRC radios and two DSRC antennas are necessary, rather than one DSRC radio and one DSRC antenna). Second, the suppliers provided estimates relating to costs of equipment they supplied, but these estimates did

[313] Because this table is the first time we break out the costs of the individual pieces of in-vehicle V2V equipment, we also use this table to roster the weight of each of the individual pieces as well as the cost of each of the individual pieces. See Section XI.C.1.b) below for discussion of the impacts to consumer benefits of increasing vehicle weight.

not necessarily include costs for driver warnings for the safety applications that would use V2V, nor did they include labor and wiring necessary for the OEM to install the equipment into the vehicle. The information from the suppliers was thus incomplete for our current purposes, and more assumptions were needed in order to provide a more complete estimate of costs.

We also assumed that all vehicles would already have the FCW application in them by the time V2V was required in vehicles, given that the agency anticipates counting the costs and benefits for that application as part of a separate regulatory effort.[314] Thus, additional costs for displays and wiring to displays were not assumed for FCW for purposes of this analysis, meaning that the preliminary costs (and benefits) associated with requiring V2V technology are slightly lower (albeit only $1-$2) than they would have been without this assumption.

b) Preliminary Consumer costs

The costs in Table XI-3 reflect the preliminary estimated costs that the OEM pays to the supplier to obtain these components. However, they do not reflect the cost of these systems to consumers. Table XI-4 provides preliminary consumer costs for these supplier parts. To obtain consumer costs, the costs to the OEM for each variable are multiplied by 1.51 to estimate a retail price equivalent (i.e., consumer cost). The agency uses the 1.51 markup to represent fixed costs (research and development, selling and administrative costs, etc.), as well as OEM profits, transportation costs, and dealer costs and profits. Additional costs to consumers (e.g., installation costs) are estimated separately and further discussed later.

Table XI-4 Preliminary Consumer Costs (for just supplier parts) Per Vehicle (2012 dollars)

Component	**Consumer Cost** (2012 dollars)
DSRC Transmitter/Receiver (2)	196.3
DSRC Antenna (2)	15.10
Electronic Control Unit	67.95
GPS	21.14
GPS Antenna	6.04
Wiring	13.59
Displays	7.24
Total	327.13

[314] This assumption may change. If NHTSA does not require FCW in a regulatory action prior to any V2V regulatory action, the costs of benefits of FCW may, at least in part, be attributed to V2V.

c) *Additional Detail on Preliminary Display Costs*

A further breakdown of costs that are already included in Table XI-3 and Table XI-4 is provided in Table XI-5 below, where additional detail on our estimates for weight and costs of displays are shown. Cost information gathered for displays include both manufacturer-produced and supplier-provided displays, as well as different types of displays (e.g., display lights, malfunction lights) that can be used by the safety applications to inform drivers of potential dangers identified by V2V communications. One such display, a heads-up display (i.e., one displayed on the windshield in the driver's field of vision), is a more expensive system, as shown in the cost tear-down results for two heads-up display systems (see Table XI-5 below).

Table XI-5 Preliminary Estimates of Display Costs (2012 dollars)

	Weight (lb.)	Variable Costs	Consumer Costs
Five display lights[315]	.05	$1.00	$1.51
Malfunction light[316]	.01	$1.29	$1.95
Light bar	.20	$2.50	$3.78
Total	.26	$4.79	$7.24
Info. not used			
Heads-up display Volvo S8[317]	.17	$6.91	$10.43
Heads-up display Ford Taurus[318]	.16	$12.67	$19.13

Warnings can be presented to the drivers via different modalities (e.g., auditory, visual, haptic) and for our analysis, the following assumptions and inclusions were made:

- Auditory Displays: We did not include any cost for audible warnings at this time, based on the assumption that any audible warnings required for a V2V system would use existing audible warning equipment already in the vehicle at that point. If more refined warnings were to be required, that would add costs.
- Visual Displays: We assume very simple visual display lights for five applications, including EEBL, DNPW, BSW/LCW in the A-pillar or side view mirror (one display for both, but one on each side), and LTA. Wiring to these displays is considered separately. We assume a much more complex light bar for IMA (like one used in a

[315] Five display lights is an assumption for purposes of analysis.
[316] Cost and Weight Analysis of Advanced Frontal Airbag Systems (Final Report, Volume 1, Docket number NHTSA-2011-0066-0001). See www.regulations.gov/#!documentDetail;D=NHTSA-2011-0066-0001 (last accessed Jan. 29, 2014).
[317] NHTSA FCWS Final Report, at 61/103 (May 16, 2012). See www.regulations.gov/#!documentDetail;D=NHTSA-2011-0066-0011 (last accessed Jan. 29, 2014).
[318] Id., 49

V2V demonstration vehicle that would be situated along the top of the dash next to the windshield and run up the A-pillar a little), that would attract the driver's eyes toward the direction of the encroaching car.[319] We also assume that a malfunction light would be required to tell you that the V2V system is not working and you should have your vehicle serviced.[320]

- Haptic Displays: It is also possible that some manufacturers might choose a haptic display. Even though the agency has no cost estimates for haptic displays, we believe haptic displays would typically be more costly than the displays we have included in this analysis.

d) Preliminary Installation cost estimates

The main installation cost is labor, but there are also some costs for materials used in the installation of the vehicle equipment (e.g., minor attachments such as brackets or plastic tie downs to secure wires). In the table below, estimates for installation costs are separated into "Material Costs" (for the minor attachments), "Labor Costs," and "Variable Burden" (i.e., other costs that are not direct labor or direct material used in the part, but are costs that vary with the level of production, such as set-up costs, in-bound freight, perishable production tools, and electricity). We estimate that the variable cost to OEMs to install the V2V equipment is $10.38 and that the cost to consumers will be $15.67 given the 1.51 RPE (See Table XI-6, below). Note that the weight of the installation materials is assumed to be 0.1 pounds.

Table XI-6 Preliminary Installation Cost Estimates (2012 dollars)

Part	Material Cost	Labor Cost	Variable Burden	Total Variable	Total Consumer Cost
DSRC Transmitter/Receiver	0.03	1.25	0.81	2.10	3.17
DSRC Antenna	0.03	0.10	0.07	0.20	0.30
Electronic Control Unit	0.02	1.78	1.15	2.95	4.45
GPS	0.03	0.10	0.07	0.20	0.30
GPS Antenna	0.03	0.10	0.07	0.20	0.30
Wiring	0.18	0.88	0.57	1.63	2.47
Five Displays + Malfunction Disp.	0.00	0.61	0.39	1.00	1.51
Light Bar	0.03	1.25	0.81	2.10	3.17
Total	0.36	6.07	3.94	10.38	15.67

[319] Some manufacturers might choose to use a heads-up display system for V2V warnings, but the agency does not consider it necessary at this time, and it has therefore not been included for purposes of the current analysis. See Section XI.C.1.c) for further heads-up display costing information.

[320] The agency notes this would be a minimal approach to malfunction indication and that other, more explicit, malfunction warnings could potentially be developed.

Generally, the ideal source of information for installation costs is a cost teardown study. However, we do not have a teardown study for V2V parts, in part because there are no production-volume systems yet to analyze: it is difficult to tear down something that does not exist. Thus, we examined a similar installation cost-estimation teardown analysis. Installation costs were taken from a 2012 report titled "Cost, Weight & Lead Time Analysis of Lane Departure Warning Systems and Lane Keeping Systems Technology Associated with Passenger Vehicles," by Lieberman & Associates.[321] While the parts are not the same, we believe that the process for installing these parts would have similar material, labor, and variable burden costs. The cost estimates in this report are in 2011 dollars, so they were multiplied by the GDP deflator (115.338/113.369 = 1.0178) to bring them up to 2012 dollars.

Specifically, in this report, costs are estimated for installing back-up systems (e.g., a camera, ECU, displays) into six different make/models of vehicles. While the system examined in the Lieberman & Associates report contains different components from the V2V system (e.g., the V2V system uses a DSRC radio instead of a camera), we believe that the installation burden for these components is similar. With both systems, manufacturers receive these components from suppliers and are installed using similar tools.

In addition to using the cost estimates from the Lieberman study, a few assumptions were made in our analysis. For wiring, we assumed a variable labor cost of $21.14.[322] We also assumed that these new wires would be combined with other wiring harnesses, so the incremental cost would be the time to identify and hook up the wires, at 10 seconds per wire to hook up both ends and with a total of 15 separate wires that would need to be installed (seven for displays and malfunction lamp and eight between the two DSRC radios, two DSRC antenna, GPS, GPS antenna, amplifier, and ECU).

e) Current GPS installation rate

While the supplier costs and the installation costs are both costs that are incurred in order to install the components necessary to support V2V safety applications, many vehicles are already being equipped with GPS units. For those vehicles, the GPS component of the V2V system is not a cost that is attributable to the V2V system, since the current information available

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[321] Docket No. NHTSA-2011-0066-0033. See www.regulations.gov/#!documentDetail;D=NHTSA-2011-0066-0033. Available at www.regulations.gov/contentStreamer?objectId=090000648 11e9b8c&disposition=attachment&contentType=pdf [Note: There is a discrepancy in the title of this report, one version of which omits the word "Weight."]

[322] Production Occupations, 51-2099 Assemblers and Fabricators, Motor Vehicle Manufacturers (Bureau of Labor Statistics, May 2012). See www.bls.gov/oes/current/oes512099.htm (last accessed Jan. 28, 2014).

to the agency indicates that navigation-grade GPS units are sufficient for the V2V safety applications.

For MY2011, NHTSA estimates that about 50 percent of the new light vehicle fleet has GPS (and a GPS antenna) in their vehicle (see Table XI-7 below). This estimate is based on: (1) information about vehicles with navigation systems, which is contained in Wards Automotive Yearbook 2012 that has MY2011 data on factory-installed equipment such as navigation (NAV); and (2) assumptions about OEM Automatic Collision Notification systems (like OnStar), which have GPS as part of the system. An estimated 18 percent of MY2011 light vehicles have navigation systems. In addition, a high proportion of BMW, Ford, and GM vehicles have ACN, and other manufacturers (Toyota and Hyundai) have similar systems. However, we do not have information on what percent of their vehicles are covered now. It is nevertheless likely that more than 50 percent of the new light vehicle fleet already have GPS, and would not need to spend additional money on GPS for V2V. This estimate of the current market penetration of GPS systems is, therefore, subtracted from the total costs of equipping all vehicles with V2V safety applications in this analysis. However, if the data indicate that more advanced GPS systems are necessary, then we would need to revisit these cost assumptions.

Table XI-7 Estimated Percentage of GPS in the New Vehicle Fleet

Passenger Cars			LTV			TOTAL		
MAKE	NAV %	NAV + ACN EST.	MAKE	NAV %	NAV + ACN EST.	MAKE	NAV %	NAV + ACN EST.
BMW	22%	100%	BMW	39%	100%	BMW	31%	100%
CHRYSLER	24%	24%	CHRYSLER	24%	24%	CHRYSLER	24%	24%
FORD	5%	80%	FORD	14%	80%	FORD	11%	80%
GM	7%	90%	GM	18%	90%	GM	14%	90%
HONDA	12%	12%	HONDA	38%	38%	HONDA	25%	25%
HYUNDAI	8%	8%	HYUNDAI	7%	7%	HYUNDAI	8%	8%
JAGUAR	100%	100%				JAGUAR	100%	100%
			LAND ROVER	84%	84%	LAND ROVER	84%	84%
MAZDA	6%	6%	MAZDA	35%	35%	MAZDA	15%	15%
MERCEDES	54%	54%	MERCEDES	66%	66%	MERCEDES	61%	61%
MITSUBISHI	8%	8%	MITSUBISHI	14%	14%	MITSUBISHI	10%	10%
NISSAN	15%	15%	NISSAN	39%	39%	NISSAN	24%	24%
PORSCHE	35%	35%	PORSCHE	37%	37%	PORSCHE	36%	36%
SAAB	10%	10%				SAAB	10%	10%
SUBARU	6%	6%	SUBARU	41%	41%	SUBARU	28%	28%
SUZUKI	6%	6%	SUZUKI	0%	0%	SUZUKI	5%	5%
TOYOTA	8%	8%	TOYOTA	24%	24%	TOYOTA	15%	15%
VW	10%	10%	VW	48%	48%	VW	14%	14%
VOLVO	35%	35%	VOLVO	35%	35%	VOLVO	35%	35%
TOTAL	11%	36%	TOTAL	23%	59%	TOTAL	18%	49%

f) Summary of new vehicle V2V weight and cost estimates

Table XI-8 summarizes the variable and consumer costs for original equipment manufacturers for the first year. Costs are assumed to decrease in years after the initial year based on the learning curve.

Table XI-8 Summary of Cost Estimates in Year 1 for New Vehicles

(2012 dollars)

	Weight (lb.)	Variable Costs	Consumer Costs
Supplier	3.23	$216.79	$327.36
Installation	0.36	$10.38	$15.67
Subtotal	3.59	$227.17	$343.03
Minus Current GPS Installation	0.14	-$9.20	-$13.89
Total	3.45	$217.97	$329.13

2. Aftermarket devices

Preliminary costs are estimated for the three possible aftermarket V2V systems described in Section XI.C: Retrofit, Self-contained, and Vehicle Awareness Device (VAD).

The same two suppliers provided cost estimates for these three types of aftermarket devices. NHTSA asked them to provide estimates assuming both that they were sold individually, and in groups of 1,000 units to retailers or to other large purchasers. NHTSA developed likely estimated costs for these three types of aftermarket devices, using these estimates and other NHTSA estimates based on the same rationales used previously to estimate new vehicle costs. The next three tables show the estimated consumer costs.

Basic assumptions used in each of these estimates are:

- For aftermarket devices sold individually, we assumed a markup factor of 1.5 from variable costs to consumer costs;
- For aftermarket devices sold as an order of 1,000 or more products, we assumed a markup factor of 1.3 from variable costs to consumer costs;
- That the learning curve will apply to aftermarket devices also, since their main components will be the same as the OEM components of DSRC transmitter/receiver and antenna.

Table XI-9, Table XI-10, and Table XI-11 provide the estimated consumer component costs and weight for all three aftermarket device types. These are just equipment costs and do not include the costs of installing the equipment into used vehicles.

Table XI-9 Estimated Consumer Cost of Aftermarket Equipment – Retrofit Device (2012 dollars)

Component	Weight	Cost Per Unit for	
	(in lb.)	1 Unit	1,000 Units
DSRC Transmitter/Receiver (2)	0.65	$144	$124.8
DSRC Antenna (2)	0.44	15	13
Electronic Control Unit	0.55	67.5	58.5
GPS	0	21	18.2
GPS Antenna	0.22	6	5.2
Wiring	0	15	13
Displays	0	22.5	19.5
Total	1.86	291.00	252.20

Table XI-10 Estimated Consumer Cost of Aftermarket Equipment – Self-Contained Device (2012 dollars)

Component	Weight	Cost Per Unit for	
	(in lb.)	1 Unit	1,000 Units
DSRC Transmitter/Receiver (2)	0.65	$114	$98.8
DSRC Antenna (2)	0.44	15	13
Electronic Control Unit	0.55	67.5	58.5
GPS	0	21	18.2
GPS Antenna	0.22	6	5.2
Wiring	0	12	10.4
Displays	0	10.5	9.1
Total	1.86	246.00	213.20

Table XI-11 Estimated Consumer Cost of Aftermarket Equipment – Vehicle Awareness Device (2012 dollars)

Component	Weight	Cost Per Unit for	
	(in lb.)	1 Unit	1,000 Units
DSRC Receiver	0.325	$52.5	$45.5
DSRC Antenna	0.22	7.5	6.5
Electronic Control Unit	0.55	0	0
GPS	0	16.5	14.3
GPS Antenna	0.22	4.5	3.9
Wiring	0	0	0
Displays	0	0	0
Total	1.32	81.00	70.20

a) Installation of aftermarket equipment

We believe that a trained technician is likely to be needed to install aftermarket equipment properly, since, as learned during the Safety Pilot Model Deployment, it is not so easy to determine where to attach antennas on the vehicle to ensure their effectiveness.[323] Typical installation times would depend on the type of aftermarket equipment. For this analysis we estimated one hour for a VAD, one hour and fifteen minutes for a self-contained device, and one hour and 30 minutes for a retrofit device. These time estimates were derived from installation times from the Safety Pilot Model Deployment. We also assume that a dealership would be the typical place where aftermarket devices could be installed. We estimate that the average charged wage rate at a dealership is about $90 per hour;[324] installation costs would likely be different if the devices were installed somewhere else.

b) Summary of aftermarket cost estimates

Table XI-12 presents preliminary consumer costs for Aftermarket in year 1, including both equipment cost and installation costs. The equipment costs will be affected by the learning curve, but installation costs (which are just labor) will not be affected by the learning curve.

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[323] Somewhere near the center of the roof, near the center of the vehicle appears to be the ideal location for the antenna to be able to pick up GPS and to talk to each other. The angle of the antenna is also important for receiving and appropriately transmitting information. This becomes difficult to determine when the shape of the roof of each make/model is different.

[324] Based on Service Repair Facility Average Hourly Labor Rates. See www.mechaniconduty.com/MapGraphic_email.pdf (last accessed Jul. 14, 2013). These appear to be repair rates from a 2009 phone survey of rates charged in particular cities, one per state. No national estimate was provided. Thus, this is a rounded number considering that we expect repair rates in rural areas to be less and rates for 2012 to be higher than the survey results.

Table XI-12 Aftermarket Consumer Cost Estimates for Year 1 (2012 dollars)

	Equipment	Installation	Total
Retrofit	252.20	135	387.20
Self-contained	213.20	112.5	325.70
VAD	70.20	90	160.20

3. How the preliminary projected vehicle equipment cost estimates were developed

a) Technology implementation scenarios

As mentioned above, we assume that the costs of the equipment needed to support V2V safety applications will decrease over time due to learning (the ability of manufacturers to realize cost savings due to their experience manufacturing the product). Thus, the costs that were estimated without including learning in the earlier sections will decrease over time if learning is considered. Because the effect that learning has on equipment prices is based on the cumulative production of the system (i.e., the total number of systems that have been produced since the system first became available for sale), we need to know what the projected sales of these systems will be in the future.

For the purposes of this analysis, we examined three scenarios of future V2V technology sales/implementation using MY2020 as the base vehicles that first have the technology. Scenario 1 presents a relatively aggressive technology implementation schedule that includes the installation of aftermarket devices. These aftermarket installations are assumed to be made on the existing relatively recently-sold model year (i.e., MY2015-2021) vehicles, but these aftermarket installations are not applied until year 2022 for a subsequent 5-year time period.

Scenario 2 presents a slower pace of technology implementation than that in Scenario 1. Furthermore, Scenario 2 does not have aftermarket device installation. Scenario 3 presents the slowest implementation and lowest among the three scenarios. Scenario 3 not only does not include the aftermarket device, its implementing rate also reaches only to a maximum of 25 percent as opposed to the 100 percent for Scenarios 1 and 2. These scenarios were all based on the projected future new vehicle sales developed by the agency. The projection starts at approximately 17 million per year in 2020 and increases to 20 million in 2050, remaining flat at the 2050 level thereafter. This projection is based on historic R.L. Polk registration data and vehicle sales from 1973 to 2012 using a linear regression statistical process.

The following summarizes the three scenarios. We note that the dates selected here are simply assumptions made for the convenience of this analysis, and reflect no judgment by the agency on timing or phase-in requirements.

(1) Scenario 1:

- 35 percent -70 percent-100 percent vehicle equipment phase-in starting in MY2020
- 100 percent installation of two safety applications for those with vehicle equipment

- Aftermarket deployment for MY2015-2021 vehicles (applicable vehicles)
    - Starting 2022 and continuing for a total of 5 years
    - 5 percent of applicable vehicles for 2022 and 2023
        - For example, for year 2022, applicable old vehicles include the survived MY2015-2019 vehicles, 65 percent of the survived MY2020 vehicles, and 30 percent of the survived MY2021 vehicles. Five percent of these vehicles would be equipped with an aftermarket device
        - For year 2023, the applicable old vehicles include 95 percent of those applicable old vehicles that were defined for year 2022 and would survive in year 2023.
    - 10 percent of applicable vehicles for 2024-2026
    - The estimated number of aftermarket sales for the 5 implementation years in this scenario are:
        - 4.70 million in MY2022,
        - 4.37 million in MY2023,
        - 8.09 million in MY2024,
        - 7.06 million in MY2025, and
        - 6.11 million in MY2026.
- ASD and VAD are assumed to have an equal penetration rate each year.

(2) Scenario 2

- 35 percent-70 percent-100 percent vehicle equipment phase-in starting in MY2020
- 50 percent installation of two safety applications for MY2020-2022 vehicles that have vehicle equipment, 60 percent for MY2023, 70 percent for MY2024, 80 percent for MY2025, 90 percent for MY2026, 100 percent for MY2027 and later.
- No Aftermarket deployment

(3) Scenario 3

- 5 percent vehicle equipment for MY2020, 15 percent for MY2021, 25 percent for MY2022 and newer vehicles
- 100 percent installation of two safety applications for those vehicles that have vehicle equipment
- No Aftermarket deployment

In order to keep preliminary costs consistently applied, when we summarize costs, aftermarket costs will be applied in the year that the aftermarket equipment is purchased even though it will not line up with the model year. For example, in 2023, we assume that aftermarket equipment will be purchased for a certain percentage of MY2015 through 2021 vehicles. That cost is spent in calendar year 2023, and will look like it is spent on MY2023 vehicles in the summary costs. The preliminary benefits will be applied by model year, since scrappage (i.e., the scrapping of discarded objects) is dependent upon model year, not when aftermarket equipment is purchased. This has a very small impact on overall costs by model year and only affects Scenario 1.

Table XI-13 below shows the number of sales of V2V equipment in new vehicles by model year (starting in 2020) for the three scenarios. As described earlier, Scenarios 1 and 3 assumed that the V2V equipment would already have the IMA and LTA applications. Scenario 2 has a separate rate for V2V equipment and applications.

Table XI-13 V2V Technology Sales Assumptions in New Vehicles (Millions of Vehicle)

Year	Model Year	Scenario 1*	Scenario 2 Equipment	Scenario 2 Applications	Scenario 3*
1	2020	5.96	5.96	2.98	0.85
2	2021	11.94	11.94	5.97	2.56
3	2022	17.21	17.21	8.61	4.30
4	2023	17.32	17.32	10.39	4.33
5	2024	17.41	17.41	12.19	4.35
6	2025	17.56	17.56	14.05	4.39
7	2026	17.65	17.65	15.89	4.41
8	2027	17.78	17.78	17.78	4.45
9	2028	17.94	17.94	17.94	4.49
10	2029	18.05	18.05	18.05	4.51
11	2030	18.22	18.22	18.22	4.56
12	2031	18.37	18.37	18.37	4.59
13	2032	18.50	18.50	18.50	4.63
14	2033	18.61	18.61	18.61	4.65
15	2034	18.79	18.79	18.79	4.70
16	2035	18.97	18.97	18.97	4.74
17	2036	19.14	19.14	19.14	4.79
18	2037	19.31	19.31	19.31	4.83
19	2038	19.47	19.47	19.47	4.87
20	2039	19.66	19.66	19.66	4.92
21	2040	19.88	19.88	19.88	4.97
22	2041	20.17	20.17	20.17	5.04
23	2042	19.51	19.51	19.51	4.88
24	2043	19.62	19.62	19.62	4.91
25	2044	19.72	19.72	19.72	4.93
26	2045	19.83	19.83	19.83	4.96
27	2046	19.94	19.94	19.94	4.99
28	2047	20.05	20.05	20.05	5.01
29	2048	20.16	20.16	20.16	5.04
30	2049	20.27	20.27	20.27	5.07

31	2050	20.38	20.38	20.38	5.10
32	2051	20.38	20.38	20.38	5.10
33	2052	20.38	20.38	20.38	5.10
34	2053	20.38	20.38	20.38	5.10
35	2054	20.38	20.38	20.38	5.10
36	2055	20.38	20.38	20.38	5.10
37	2056	20.38	20.38	20.38	5.10
38	2057	20.38	20.38	20.38	5.10
39	2058	20.38	20.38	20.38	5.10

*for both equipment and safety applications

b) Learning

As stated earlier, the preliminary cost estimates we listed above for originally-equipped V2V systems and aftermarket systems do not take into account the potential cost savings that manufacturers will realize over time. As we show in the following paragraphs, the effect of learning can lead to a significant reduction in the costs over time. If we use any of the technology sales scenarios described in the previous section (i.e., the differences between them would be slight) and assume that V2V equipment production begins in 2020 with a price of $329, the costs can range from $249 to $273 in 2022, and $185 to $199 in 2058. The estimated effect of learning to prices for aftermarket devices would decrease by 12 percent in 5 years, from $387 to $341 for a retrofit device, $326 to $287 for the self-contained device, and $160 to $141 for a VAD.

D. Projected fuel economy impact – fuel costs for increased weight

In addition to the cost of the equipment itself, the new equipment on vehicles will increase the vehicle weight. Since the increase in weight is relatively small, the increased weight will have only a small impact on the fuel economy of the individual vehicles on which the V2V equipment is installed. Nevertheless, over the lifetime of these vehicles, this impact on fuel economy will create a cost for society. Our preliminary estimates indicate that (depending on the discount rate) the fuel economy impact on passenger cars will be between $9 and $12 over the lifetime of the vehicle. For light trucks, we believe the impact will be a cost of $11 to $18 over the lifetime of the vehicle.

The impact of added weight on lifetime fuel economy is a function of mileage, survival probability (i.e., the percentage of the vehicle fleet that will not be scrapped due to an accident), the price of gasoline, the change in vehicle fuel economy due to the added weight, and the discount rate chosen to express lifetime impacts in their present value. A sample calculation for passenger cars is:

Equation XI-1 Projected Fuel Economy Impact Calculation

$$\sum_{n=1}^{37}[(V_n * S_n)/(w/(w+1))^{.8} * fe * .80 - (V_n * S_n)/fe * .80]p_n * d_n$$

Where:

n = Year

V = Vehicle miles traveled

S = Survival probability

w = Baseline vehicle weight

i = Incremental weight from adding V2V – 3.45 pounds

fe = Baseline EPA fuel economy

.80 = Factor to derive on-road fuel economy from EPA fuel economy

p = Fuel price

d = Mid-year discount factor

Each of the aforementioned variables is determined by different sources.

1. Fuel price and estimated miles per gallon

The projected price of gasoline was taken from the Energy Information Administration Annual Energy Outlook 2013 early release. This source enables us to project the likely price of fuel between now and 2057. In our cost estimates, fuel taxes are excluded since these are a transfer payment and not a cost to society. Gasoline prices and baseline fuel economy levels are projected to increase steadily throughout the time period, which means that the impact of the additional weight due to installation of V2V systems will change with every model year.

However, unlike with fuel prices, we do not have baseline fuel economy estimates past 2025. Thus, estimates of the impact on fuel prices over the lifetime of the model year were examined for 2020 and 2025. For years beyond 2025, we assume that vehicles will have the same baseline fuel economy and weight as the vehicles from MY2025. The baseline miles per gallon figures for passenger cars and for light trucks are shown in Table XI-14. These estimates reflect a weighted average based on standards in effect for those years.

Table XI-14 Estimated Miles per Gallon (MPG) Values

2020	Passenger Cars	Light Trucks
Baseline mpg on EPA test	45.1	32.8
Baseline weight (lb.)	3240	4397
2025		
Baseline mpg on EPA test	52.1	37.6
Baseline weight (lb.)	3240	4397

2. Vehicle miles traveled and survivability

NHTSA uses VMT by age of vehicle and survivability tables to model the retirement of older vehicles as time passes and to estimate the impact of fuel economy changes over the lifetime of a model year. Both VMT and survivability data differ between passenger cars and light trucks.[325]

3. Incremental weight from V2V equipment

In addition to receiving preliminary information on the vehicle equipment costs (as discussed above) from the confidential business information submissions by suppliers, we also received information on how much the V2V equipment is likely to weigh. As discussed in Table XI-3, above, the V2V equipment is likely to weigh approximately 3.23 pounds. In addition (as shown in Table XI-15), we estimate that the warning display components and installation materials will weigh approximately 0. 36 (= 0.26 + 0.1) pounds. Thus, our current estimate is that the V2V equipment necessary to support the V2V safety applications will increase the vehicle weight by 3.59 pounds. Taking into account the reduction of GPS, the net increase in weight is estimated to be 3.45 pounds. The increased weight is the same for both passenger cars and light trucks.

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[325] The survival rates (see Table A-6) were derived using the 1997-2010 R.L. Polk, National Vehicle Population Profile (NVPP). The methodology for deriving these survival rates was published in NHTSA's technical report "Vehicle Survival and Travel Mileage Schedules," Office of Regulatory Analysis and Evaluation, NCSA, Jan. 2006 (Docket No. NHTSA-2005-22223-2218). See www.regulations.gov/#!documentDetail;D=NHTSA-2005-22223-2218 (last accessed Jan. 29, 2014). Polk's NVPP is an annual census of passenger cars and light trucks registered for on-road operation in the United States as of Jul 1 each year. Survival rates were averaged for each vehicle age and up to 30 years. A polynomial model was fitted to these data using regression analysis to establish the relationships between age and the proportion of cars or light trucks surviving to that age.

For vehicle miles traveled, data from the 2009 National Household Travel Survey (NHTS) was used for this analysis. Approximately 300,000 vehicles were included in the 2009 NHTS to estimate the average number of miles driven by household vehicles at each vehicle age. An earlier survey, 2001 NHTS, was used in the 2006 NCSA technical report cited above.

Table XI-15 Summary of Incremental Vehicle Weight Due to V2V Equipment

Category	Weight
V2V Equipment Weight	3.23 lb.
Warning Display Weight	0.26 lb.
Installation Materials	0.10 lb.
Minus Current GPS Installation	-0.14 lb.
Total Incremental Weight	3.45 lb.

4. Summary of fuel economy impact

Based on all the above information (i.e., on vehicle miles traveled, survivability, projected fuel prices, projected fuel economy, and estimated increased weight), we believe that the impact on fuel economy will be as follows. For MY2020 passenger cars, we estimate that there will be a $12 increase in fuel used over the lifetime of the vehicle at the 3 percent discount rate, and $9 at the 7 percent discount rate. For MY2020 light trucks, we estimate that there will be an $18 increase in fuel used over the lifetime of the vehicle at the 3 percent discount rate, and $11 at the 7 percent discount rate. See Table XI-16, below.[326]

Table XI-16 Impact of weight increase on fuel economy over the lifetime of the model year vehicle (per vehicle cost for 3.45 lb. increase)

MY2020	**Passenger Cars**	**Light Trucks**
3% Discount Rate	$12.38	$18.56
7% Discount rate	$9.51	$11.90
MY2025		
3% Discount Rate	$11.76	$17.70
7% Discount rate	$9.04	$11.36

It appears that the improvement in fuel economy from 2020 to 2025 results in a decrease in the fuel costs, even though there is an increase in the price of fuel during the time period. While we do not have estimates of fuel economy levels or average baseline weights of vehicles in the fleet past MY2025, we will assume that the impact of the weight increase on fuel economy will stay relatively constant over the time frame.

E. Preliminary system communication costs

The DOT's Intelligent Transportation Systems Joint Program Office contracted Booz Allen Hamilton to perform a cost estimate for the communication costs. BAH provided the

[326] We have not calculated any improvements to fuel economy that may result from potential V2V and V2I applications. As briefly discussed in Section II.B.5, however, the agency expects there will be V2I mobility applications that provide fuel economy benefits. These benefits would be likely to significantly exceed these costs.

following report: "Communications Data Delivery System Analysis for Connected Vehicles: Revision and Update to Modeling of Promising Network Options."[327] In addition, BAH provided a Microsoft Excel file, titled "Cost Model for Communications Data Delivery System (CDDS)," that lays out the cost estimates (based on preliminary information) in a spreadsheet format, which allowed NHTSA to make changes to assumptions as needed and calculate costs accordingly.[328] This report takes the BAH technical report and focuses on the cases we feel are most reasonable, and presents them in a more plain language format. The next several paragraphs lay out the assumptions behind these estimates.

When a V2V-equipped vehicle is on the road, it will give a computerized message stating, "I am here, this is how fast I'm going, and so on . . . *You can trust me*." That last part of the message, where the vehicle says "*You can trust me*," is important. At the same time, the other vehicle's V2V system will be listening for the message, and it needs to know that the message is from a good source. In order to meet the agency's security needs, BAH assumed that PKI will be used.

As part of PKI, each vehicle is given a set of digital certificates, and the certificates broadcast by the device are assumed not to contain codes that could uniquely identify a vehicle like a license plate would. These anonymous certificates were assumed to last for only 5 minutes, so even if someone wanted to track a device by its certificate with sophisticated and expensive equipment, it would be even more difficult to do so for longer than 5 minutes, when the vehicle starts using a completely different certificate. This makes the system harder to break into and makes it very hard to track vehicles.

Also, under the current security model,[329] every vehicle's V2V system would keep a list of "misbehaving" certificates that it encounters. While the approach to misbehavior has not been decided, one method could be that any time bad V2V information is sent, due to an error or due to intentional human tampering, the certificate tied to that bad V2V data would be recorded and later uploaded when the vehicle transmits data to the SCMS. This way, the SCMS that handles the certificate knows which vehicle is misbehaving, and is able to put together a list of all the certificates that vehicle currently has available. Then, when vehicles connect to the system, they will be warned about these misbehaving vehicles with a list of certificates to avoid trusting. That list is called the Certificate Revocation List.

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[327] BAH CDDS Final Report. See Docket No. NHTSA-2014-0022.
[328] *Cost Model for Communications Data Delivery System (CDDS)* (Excel File) at Docket No. NHTSA-2014-0022.
[329] As discussed in Section IX, NHTSA plans to continue researching security options, including those that may be significantly less costly due to decreased reliance on burdensome distribution of CRLs.

Assuming a PKI system is used and based on the preliminary security system design used in this report, communications between the OBE and to the SCMS or "phone home" include the following activities.

- UPLOAD - a request for new certificates
- DOWNLOAD - new certificates
- UPLOAD - a misbehavior report
- DOWNLOAD – a full/partial CRL
- and conduct other data functions or system updates

The next several paragraphs detail the cost factors for these communication activities.

1. Certificate revocation list

The CRL is a list created by the SCMS that identifies vehicles that are sending out messages that are misbehaving. These vehicles could be sending out messages that erroneously alert drivers of other vehicles, either intentionally or from misbehaving sensors. BAH has outlined several ways by which vehicles may be added to the CRL, as presented below.[330]

- Administrative revocation, which would be based on a pre-determined set of criteria, not based on actual misbehavior. For example, vehicles that are formally retired, or otherwise determined to be removed from the system for non-misbehaving reasons, could make up entries on the CRL.
- Vehicles that observe other vehicles distributing obviously erroneous messages report those vehicles. These observations would be based on plausibility checks that would verify if the message content made physical sense.
- All vehicles report any received message that results in a positive application action (i.e., any message that provides an alert to the driver and a commensurate action). For example, if an in-vehicle application issued a warning to the driver based on a received message, that message would be sent to the Misbehavior Authority (MA). This approach would identify as misbehaving vehicles that were emitting messages that passed plausibility checks but were potentially erroneous to the extent that they were causing a large number of warnings.
- Vehicles randomly select received messages to send to the MA, and the MA would seek to identify trends and patterns from the randomly sampled messages.[331]

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[330] BAH CDDS Final Report at 47 at Docket No. NHTSA-2014-0022

[331] Unless the sampling rate is high, the overall effectiveness of this approach is uncertain. If the misbehavior rate is 1% (maximum assumed level), and the sample rate is 1%, the n this approach will, on average, detect 0.01% of the misbehaving vehicles, assuming the detection process is 100 percent effective. If the sample rate is higher, the n the sampling process will represent a greater data load than the CRL.

- It is also possible that a vehicle could self-report if it determines that it is not operating properly, and this might also result in a revocation.

BAH has outlined several problems that could arise as a result of misbehaving messages. If a message is received from a vehicle that is on the CRL, that message is ignored. However, if it is not on the CRL, the message would need to be checked for misbehavior. BAH has outlined the responses to these scenarios.[332]

- The result of receiving a message from a legitimate, non-misbehaving vehicle will depend on the vehicle situation.
  - If the data in the message indicates a danger, then the vehicle warning system will take positive action (warn the driver).
  - If the data in the message indicates no danger, then the system will take no action (no warning will be issued).
- The result of receiving a message from a misbehaving vehicle that is not on the CRL and which passes the plausibility tests will also depend on the vehicle situation.
  - If the data in the message indicates a danger, then the system will take positive action (warn the driver).
  - If the data in the message indicates no danger, then the system will take no action (no warning will be issued).

Attacks on the CRL have been considered by BAH. The BAH CDDS final report recognizes four types of attackers.[333]

- A1 (Clever Outsider): A talented engineer and/or cryptographer who does not possess any inside knowledge.
- A2 (Knowledgeable Insider): An insider who possesses detailed knowledge about the system (security and non-security related) and has access to its specifications.
- A3 (Funded Organizations): An organization that has access to substantial resources and furthermore possesses the capabilities of attacker A2.
- A4 (Certificate Authority insider): An insider who possesses detailed knowledge about the system and has access to confidential information at the CA level. A4 is an insider at the CA and as such compromises the root of trust of the V2V communication system.
    - Because it is the CA's responsibility to guard against such an attacker, A4 is considered out of scope.

[332] BAH CDDS Final Report at 49 at Docket No. NHTSA-2014-0022
[333] BAH CDDS Final Report, at 51 at Docket No. NHTSA-2014-0022

Finally, BAH referenced a DOT report that identified two primary security risks:[334]

- **Attacks on the user/risks to safety and user acceptance:** these attacks are aimed at users and directly impact user safety and indirectly impact system acceptance.
- **Attacks on the communications system/risks to privacy:** these attacks could either (1) track the location and driving routes of a person; (2) cause the a vehicle to be falsely reported for misbehavior, causing a valid driver to be removed from the system.

Other types of attacks, such as cyber-attacks across the entire vehicle fleet, have been considered but not yet addressed. These attacks will be addressed at a later date.

For the Communications Data Delivery System (CDDS), CAMP and BAH have made several considerations regarding design and implementation. CAMP has considered a two-phased deployment strategy, with the first phase being "initial deployment" and the second phase being "full deployment." Initial deployment refers to the first three years of SCMS implementation. The key distinction between the two phases is that in the initial deployment stage, "communications between devices and SCMS will not be generally available…" [335] because the communication network will not be established.

Initial deployment is assumed to last for three years, and requires that OBEs on newly manufactured vehicles download a three-year batch of certificates. These batches would include reusable, overlapping five-minute certificates valid for one week. The term "overlapping" in this context refers to the fact that any certificate can be used at any time during the validity period. The batches would be good for one week and at this point are assumed to be around 20 certificates per week, which equates to 1,040 for one year of certificates. As the frequency of the certificate download batch changes for full deployment, the number and therefore size of the certificate batches also changes accordingly.[336]

Certificate Updates – the download frequency of certificates at full deployment has yet to be determined. However, BAH did consider download size. For option 1, the largest download would be 3,000 certificates (for any frequency of downloads), and the largest download for

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[334] *An Approach to Communications Security for a Communications Data Delivery System for V2V/V2I Safety: Technical Description and Identification of Policy and Institutional Issues* (FHWA, Nov. 2011) at http://ntl.bts.gov/lib/43000/43500/43513/FHWA-JPO-11-130_FINAL_Comm_Security_Approach_11_07_11.pdf (last accessed Jan. 29, 2014).
[335] BAH CDDS Final Report, at 22 at Docket No. NHTSA-2014-0022.
[336] BAH CDDS Final Report at 15 at Docket No. NHTSA-2014-0022.

option 2 would be 6,000 certificates (with a three-year download). BAH also considered 2-year downloads.

Misbehavior Detection – the BAH preliminary cost analysis assumed that the device would perform a plausibility check on incoming messages. If the message is deemed implausible, the device would report it as misbehaving. This report would then be checked by the Misbehavior Authority of the SCMS, which would revoke the misbehaving vehicle's certificates if the report was deemed to be accurate.

Certificate Revocation and Certificate Revocation List – the revocation process has not yet been finalized. The BAH analysis assumed that any devices that are misbehaving would be added to the CRL, which would be sent to the OBE at regular intervals. After certificates expire, they would be removed from the CRL.

Internal Blacklist – This would be used by the SCMS to make sure that an OBE asking for new certificates is not on the revoked list. If a vehicle or device is on the list, no certificate updates will be issued.

2. Alternative communication systems

Two definitions are needed to prevent confusion among terms:

- Roadside Equipment (RSE) – refers to communication equipment on the side of the road designed to receive and send communications between vehicles and the SCMS regarding certificates, CRL, etc.
- Infrastructure Equipment (I) – refers to equipment on curves or at intersections designed to communicate information about the road or whether a light is green or red, etc. to a vehicle.

For system design specifications, BAH considered three network protocols, cellular, hybrid, and DSRC for the CDDS. The three protocols are based on different combinations of network technology that may be used by the CDDS.

- **Cellular.** This protocol would use an almost-all cellular network for the communications between the SCMS and the OBE on the vehicle. BAH also included an option to use satellite communication for a way to distribute the CRL. However, satellite communication is even more expensive than cellular, and was not considered further. BAH also noted that this protocol does not use RSE. It uses DSRC for V2I (if the infrastructure already has the DSRC antenna in it) and V2V safety communications.
- **Cellular/Wi-Fi/DSRC - Hybrid.** The second protocol would use combinations of more technologies – OBE, RSE, cellular, and satellite. DSRC and Wi-Fi would be

used when beneficial, while cellular technology would be the most used. It also uses DSRC for V2V and V2I communications.

- **DSRC.** The third protocol would use no cellular technology, and uses DSRC for V2V communications and for OBE to SCMS communications through RSE.

BAH concluded that both the cellular and hybrid protocols, the latter of which included cellular as an option, would not meet the recommend security level for the purposes of the study. Additionally, it was determined that any estimated costs to bring these two options to the required security requirements were not considered. More discussion on the estimated costs for the three network protocols is addressed later in this section.

3. System requirements/network options

This section will discuss in more detail the technology considered and the requirements that BAH assumed the system must meet. As previously mentioned, the BAH research considered three protocols for the CDDS. While the cellular and hybrid protocols were deemed not to meet the security requirements necessary for the system, this section will still discuss cellular, Wi-Fi, satellite, and DSRC technologies.

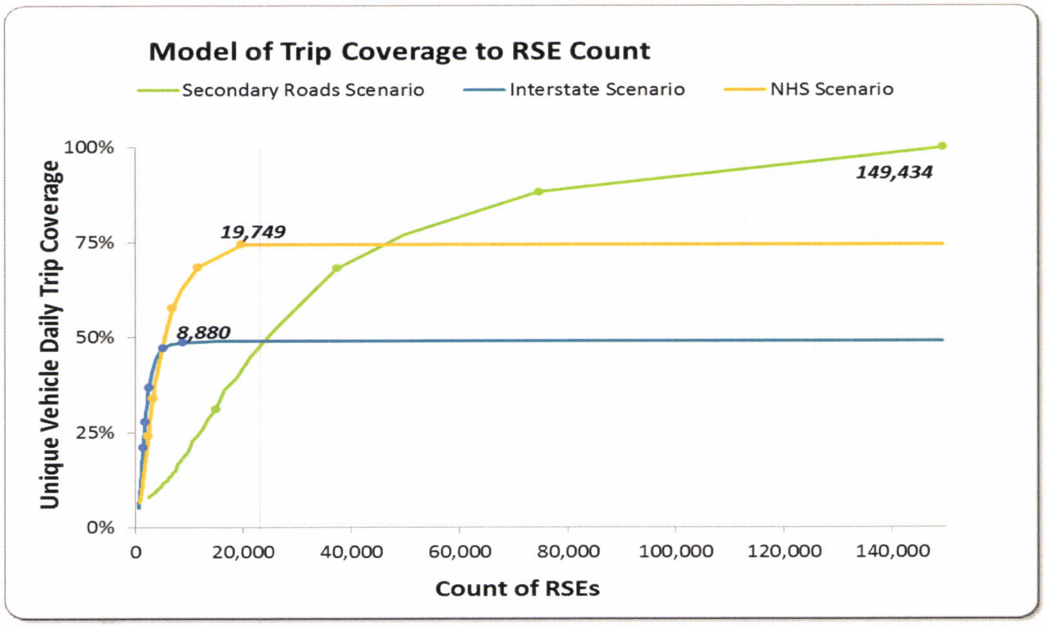
DSRC is a technology that provides local, low latency network connectivity. It allows nearly instant network connections and broadcast messaging that requires no network connection. BAH stated in its report that DSRC cannot support a full CRL update (assuming a large fleet of vehicles with a misbehavior rate of 0.1 percent) if the vehicle passes an RSE at more than a few miles per hour. In order for a vehicle to receive a full CRL update, it must therefore pass by more than one RSE per day, and any update process would have to support incremental updates. BAH suggested that a typical system would require 40 seconds to complete a full CRL update, and a vehicle would only be in the footprint for 14 seconds in the absence of congestion. However, the DSRC technology would be able to support incremental updates.

Of course, any DSRC protocol requires RSE to connect to. In order to determine how many RSE would appear to be optimal for DSRC communications, BAH considered three types of deployment options for "CRL" and "no CRL" scenarios. Deployment of RSEs was considered on three different types of roads: secondary roads, interstate highways, and National Highway System roads. Each type is defined by BAH as the following:[337] Secondary roads refer to collector roads, State highways, and county highways that connect smaller towns, subdivisions, and neighborhoods. Interstate highways are the network of freeways that make up Dwight D. Eisenhower National System of Interstate and Defense Highways. The NHS roads are the collection of interstate highways, principal arteries, strategic highways, major network connectors, and intermodal connectors. The usage of NHS roads (with 19,749 sites) was deemed

[337]BAH CDDS Final Report, at 27. See Docket No. NHTSA-2014-0022.

the most logical because it achieves greater coverage than the interstate option (with 8,880 sites) while also requiring fewer RSE than secondary roads (with 149,434 sites) to achieve the same coverage, as shown below in Figure XI-1.

Figure XI-1 Coverage of RSE by Road Type



BAH used spatial optimization and information from the 2009 National Household Transportation Survey (NHTS) to estimate the required number of RSE to achieve the desired amount of coverage. As shown, NHS roads are the most realistic scenario, though secondary roads could achieve more coverage given more resources. Ultimately, the NHS road deployment method was deemed to be the most realistic.

Cellular technology was also considered for the CDDS system. Cellular systems are very common throughout the nation and are continuing to expand. In particular, the advancement of LTE (long-term evolution) technology is helping to deliver larger amounts of data to cellular users more quickly. However, BAH stated that this is less effective when a user is moving, and that the data rate for LTE is often much lower than what is theoretically possible. Although LTE would be able to support the full download of CRL due to the expansiveness of cellular networks, there are areas where cellular networks are not available, and coverage can experience dead spots at times. Another issue that may arise is the fact that any LTE system may suffer from capacity issues in any area that has many LTE users. Though cellular could potentially be a viable option for coverage, the BAH research concluded that cost and security issues make it an unrealistic option for the CDDS.

Wi-Fi technology supports wireless connectivity and generally higher data rates. The main drawback of Wi-Fi is its design for stationary terminals. Though Wi-Fi offers higher data rates than other options, it does not work nearly as well with moving terminals. In addition, any vehicle that enters the Wi-Fi hotspot must give its MAC (media access control) address and obtain the MAC address of all other vehicles in the hotspot before it can send communications. Though it uses the same basic radio system as DSRC, DSRC eliminates the need for users to gather MAC addresses before communication. In general, this means that Wi-Fi cannot support data exchanges with vehicles moving at road speeds. The costs and security risks associated with cellular also apply to Wi-Fi.

Satellite radio, or Satellite Digital Audio Radio Service (SDARS), uses satellites to provide digital data broadcast service. SiriusXM claims the following coverage capability.[338]

- 3,717,792 mi^2 (9,629,044 km^2) of "seamless" nationwide coverage (approximately 98% of the U. S. land mass)
- 200 miles (322 km) off-shore coverage
- Comparison with terrestrial radio coverage of 50-100 miles (80-160 km)

However, BAH suggested that SDARS could not support the download of a full CRL because the download time would be longer than the average trip. If an incremental system is used, however, it could support updates. The costs and security risks associated with cellular also apply to satellite.

BAH considered misbehavior rates at three levels: 1 percent, 0.5 percent, and 0.1 percent. There is no way to accurately predict the misbehavior rate. The capabilities of the system to deliver the required amount of data to vehicles on a daily basis can be influenced by a change in the misbehavior rate and its influence on the size of the CRL. In a heavy data-requirement scenario (1 percent annual revocation rate, 3 year certificate lifetime, CRL updated daily), the BAH analysis estimated that the system would need to be able to deliver 150 MB of data to each vehicle every day. This could lead to a significant difference in costs if using commercial services such as cellular instead of DSRC. Because of the potential of significant cost increases due to data volume, BAH considered three ways to reduce CRL distribution communication load.

1. Balance certificate lifetime with CRL size. When certificates expire, there is no need for them to be retained on the CRL. As a result, reducing the lifespan of certificates would also reduce the size of the CRL.

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[338] SiriusXM Web site. See www.siriusxm.com/whatissiriusxm (last accessed Jan. 29, 2014).

2. Eliminate redundancy in the distributed CRL. If a vehicle can observe and report its own misbehavior, it would be able to stop transmitting messages and would be ignored by other vehicles without needing to check the CRL.
3. Incremental CRL updates. Theoretically, a vehicle would only need to download the changes to the CRL since its last update, rather than the entire CRL each time. A vehicle driven every day would only have to receive a single day's worth of updates. However, if a car has not been driven in a longer period of time, the update will be larger, and will be susceptible to receiving bad messages until it is fully updated, though the small size of the updates would likely mean that these vehicles could be updated quickly.

a) Transmission method

There are many communication systems that could be used to update the on-board equipment on a vehicle. This includes using DSRC, Wi-Fi, satellite, and cellular. Each one requires its own special antennae on the OBE in order to work.

By using the RSE, small base stations could be set up that would allow the vehicles to "phone home" using DSRC, but in order to make sure that the V2V system can constantly be listening for safety component update related communications, a separate DSRC antenna will be used exclusively for communicating updates. We also assume a separate DSRC and antennae will be used for communication when vehicle talk to other vehicles and send the basic safety message.

An alternative would be to install a Wi-Fi, cell, or satellite receiver that does the communication part of the work. In this case, the major factors that affect the cost are the capital needed up front to install the RSE, and the continuing fixed costs to make sure that they are running correctly.

b) Cost model

The cost model has to take into account a lot of choices based on preliminary information on how the V2V equipment can update itself, what needs to be updated, and how often it needs to update itself. BAH has developed a cost model that relies on a set of assumptions to estimate costs for 40 years. Unless otherwise stated, all cost calculations have been made with the assumptions from Table XI-17.

Table XI-17 Cost Assumptions

Component	Current Assumption Choice
OBE Deployment Scenario	Technology Sales Scenario 1
Discount Rate	0%
Certificate Option	Option 2
Certificate Phase-In Period	3 years
CRL Type	Full CRL
Misbehavior Rate	0.10%
Cellular Data Price	$4.00/GB
Cellular Component Cost on the Vehicle	$10.00
Fraction of Data Shifted from Cellular in Hybrid	67%
RSE Phase-In Period (Years)	15 years
# Nationwide RSEs	19,750
RSE Replacement Cost	$22,719
RSE Life	15 years

Below, the preliminary costs of each protocol are broken down. For cellular and hybrid we include the cost of OBE to allow the system to receive and transmit either through cellular or Wi-Fi. For the DSRC option the cost of OBE (DSRC) has already been accounted for in a previous cost section.

The costs of an OBE for cellular are estimated at $10, the cost for Wi-Fi is estimated at $2 per vehicle, and the OBE costs for a satellite system are estimated at $20. The total OBE costs for cellular are $10 per vehicle, and for hybrid are $12 to cover both cellular and Wi-Fi.

Table XI-18 OBE Subcomponent Cost Estimate

		Included in:		
OBE Subcomponents	**Cost**	**Cellular**	**Hybrid**	**DSRC**
Cellular	$10	1	1	
Wi-Fi	$2		1	
Satellite	$20	0	0	0
	Total Cost	$10.00	$12.00	$0.00

c) Cellular

Using cellular technology for the CDDS yields two primary cost drivers. The first is an estimated $10 per vehicle for cellular capability to be added to new vehicles and the second is the communication cost for cellular data. At $4.00/gigabyte,[339] data prices for cellular based system such as the CDDS end up being very high. Table XI-19 below shows total estimated costs for using a cellular protocol.

Table XI-19 Total Estimated Costs - Cellular

Cellular Costs	Year 1	Year 10	Year 20	Year 30	Year 40
RSE	$0	$0	$0	$0	$0
OBE	$171,592,000	$214,975,560	$250,550,574	$263,808,243	$269,308,171
Cellular Data	$0	$444,704,378	$1,088,849,075	$1,398,075,958	$1,607,213,512
Satellite	$0	$0	$0	$0	$0
Total	$171,592,000	$659,679,938	$1,339,399,649	$1,661,884,202	$1,876,521,682

d) Hybrid

The hybrid protocol uses both cellular technology and opportunistic use of Wi-Fi networks. The estimated data costs using this protocol are lower for cellular, but total estimated costs still remain high, as shown in Table XI-20.

Table XI-20 Total Estimated Costs - Hybrid

Hybrid Costs	Year 1	Year 10	Year 20	Year 30	Year 40
RSE	$0	$0	$0	$0	$0
OBE	$205,910,400	$257,970,671	$300,660,689	$316,569,892	$323,169,805
Cellular Data	$0	$148,234,793	$362,949,692	$466,025,319	$535,737,837
Satellite	$0	$0	$0	$0	$0
Total	$205,910,400	$406,205,464	$663,610,380	$782,595,212	$858,907,642

As indicated in the table, the estimated cellular communication costs are lower for this protocol than a pure cellular protocol, but the OBE costs are higher due to the increased per-OBE cost which would need to contain Wi-Fi capability. For the cellular approach, each OBE is estimated to cost $10, but in the hybrid approach, each OBE is estimated at $12. The hybrid approach offers an interesting alternative to the pure cellular approach, but total costs remain high. As a result, it is a less attractive option than DSRC.

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[339] BAH CDDS Final Report, Table 37 at 86 at Docket No. NHTSA-2014-0022

e) DSRC

DSRC communications are allowed by the installation of RSEs on highways. The DSRC protocol option has total estimated costs that are much lower than the other two protocol designs, as shown in Table XI-21.

Table XI-21 Total Estimated Costs – DSRC

DSRC Costs	Year 1	Year 10	Year 20	Year 30	Year 40
RSE	$0	$135,137,904	$177,681,184	$177,681,184	$177,681,184
OBE	$0	$0	$0	$0	$0
Cellular Data	$0	$0	$0	$0	$0
Satellite	$0	$0	$0	$0	$0
Total	$0	$135,137,904	$177,681,184	$177,681,184	$177,681,184

The only cost driver for using the DSRC protocol is the installation of RSEs on highways. There is no usage of cellular, Wi-Fi, or satellite data, and as a result costs are much lower. RSE costs are broken down below in Table XI-22. There are three costs relating to RSEs. The initial installation cost is estimated at $8,839 per site. It is assumed that each site would have to be replaced 15 years later, and there is an annual recurring maintenance cost of $7,482 per site.

At this point, we assumed that RSEs will get a linear phase-in over 15 years. For the first three years, there will be no RSE installations. We assume that the initial vehicles will be sold with 3 years of certificates and they will not need updates until the end of year 3. In addition, there will be so few vehicles on the road with DSRC that a CRL will not be particularly valuable, and there will be little need to communicate a CRL. The work is therefore divided into 15 parts. For the first three years, no RSE will be installed; during year four, 4/15ths of the RSEs will be installed; and 1/15 of the RSEs will be installed every year after that, until by year 15, all RSEs in the design will be installed. Assuming full deployment, the estimated number of necessary RSEs would be 19,750. That number of RSEs would be able to cover 74 percent of the nation's population every day.

Table XI-22 Road Side Equipment Cost Estimates

Average Costs per RSE	Cost
Average One-Time Cost	$8,839
Average Regular Replacement Cost	$22,719
Average Annually Recurring Cost	$7,482

If we examine just the likely communication costs on a per-vehicle basis, the cellular communication costs grow significantly over time as the number of vehicles that must be communicated with grows. Costs per vehicle are shown in Table XI-23.

Table XI-23 Communication Data Cost Estimate per Vehicle

Cellular Data Cost per Vehicle	Year 10	Year 20	Year 30	Year 40
Cellular	$2.58	$4.04	$4.57	$4.90
Hybrid	$0.86	$1.35	$1.52	$1.63
DSRC	$0.00	$0.00	$0.00	$0.00

The RSE per vehicle costs in each technology sales scenario were calculated in Table XIII-1 in Appendix A. It is assumed that these costs would be paid for at the time the vehicle is purchased or at the time the aftermarket equipment was purchased. Because 4/15ths of the RSEs are assumed to be installed in year 4 and RSEs would be replaced every 15 years, the replacement costs are higher in year 19 and year 34. Total costs increase over time for a number of years because more RSEs are working and they encounter maintenance costs.

Table XI-24 provides the total preliminary costs for each communication protocol. As indicated in the table, the costs using the DSRC protocol are considerably lower than costs under the other two protocols. Furthermore, DSRC communication is believed to meet security requirements, thus it becomes a realistic choice for CDDS.

Table XI-24 Total Communication Cost Estimates per Year by Scenario

	Cellular	Hybrid	DSRC
Year 1	$172 M	$206 M	$0 M
Year 2	$218 M	$262 M	$0 M
Year 3	$221 M	$265 M	$0 M
Year 4	$316 M	$332 M	$186 M
Year 5	$366 M	$346 M	$86 M
Year 6	$430 M	$365 M	$96 M
Year 7	$453 M	$326 M	$106 M
Year 8	$518 M	$352 M	$115 M
Year 9	$587 M	$379 M	$125 M
Year 10	$660 M	$406 M	$135 M
Year 11	$735 M	$435 M	$145 M
Year 12	$811 M	$464 M	$155 M
Year 13	$886 M	$492 M	$165 M
Year 14	$959 M	$519 M	$175 M
Year 15	$1,031 M	$546 M	$184 M
Year 16	$1,100 M	$573 M	$169 M
Year 17	$1,166 M	$598 M	$148 M
Year 18	$1,228 M	$621 M	$148 M
Year 19	$1,286 M	$643 M	$252 M
Year 20	$1,339 M	$664 M	$178 M
Year 21	$1,390 M	$683 M	$178 M
Year 22	$1,439 M	$703 M	$178 M
Year 23	$1,468 M	$708 M	$178 M
Year 24	$1,502 M	$721 M	$178 M
Year 25	$1,533 M	$732 M	$178 M
Year 26	$1,561 M	$744 M	$178 M
Year 27	$1,586 M	$753 M	$178 M
Year 28	$1,612 M	$763 M	$178 M
Year 29	$1,638 M	$773 M	$178 M
Year 30	$1,662 M	$783 M	$178 M
Year 31	$1,684 M	$791 M	$163 M
Year 32	$1,702 M	$798 M	$148 M
Year 33	$1,718 M	$803 M	$148 M
Year 34	$1,734 M	$809 M	$252 M
Year 35	$1,748 M	$814 M	$178 M
Year 36	$1,761 M	$818 M	$178 M
Year 37	$1,772 M	$822 M	$178 M
Year 38	$1,869 M	$856 M	$178 M
Year 39	$1,876 M	$859 M	$178 M
Year 40	$1,877 M	$859 M	$178 M

f) CRL type

BAH found that one input assumption was "highly uncertain and highly impactful on the … cost analysis." That input is the type of Certificate Revocation List. By choosing a different type of CRL update to the V2V device, you can significantly change the cost to keep devices safely updated. The two types of CRL update that BAH considered were "Complete Daily CRL" update and "Incremental Daily CRL" update. For the first option, Complete Daily CRL, the entire list is downloaded to the vehicle every day. In the Incremental Daily CRL, only the *changes made to the list* are downloaded. Thus, somewhere close to only 1/365 (0.27 percent) of the Complete CRL needs to be downloaded daily for the Incremental CRL update. Because the Complete Daily CRL downloads are always much bigger than the Incremental Daily CRL download, the Complete Daily option costs more than the Incremental CRL. Since the Incremental Daily CRL cost would be almost as low as having no CRL at all, rather than speculate on the small increment in cost, the cost estimates presented here include two options: Full CRL and No CRL, describing the extreme cases of how much the CRL will cost. These CRL download costs only apply to cellular and hybrid. We assume that there is no cost for DSRC with RSE because there are no anticipated per transmission costs associated with DSRC communication, as compared to the other communication mediums used in cellular and hybrid.

Total estimated costs per year are further broken down in Table XI-25 below. There are no communication costs in the first three years in the DSRC with RSE option. The cellular and hybrid (cellular and Wi-Fi) options have costs in the first three years due to OBE costs.

Table XI-25 Total Cost Estimates Comparing Full CRL to No CRL in Millions (2012 dollars)

Total costs	Year 1	Year 10	Year 20	Year 30	Year 40
Cellular No CRL	172 M	215 M	251 M	264 M	270 M
Cellular Full CRL	172 M	660 M	1339 M	1662 M	1877 M
Hybrid No CRL	206 M	258 M	301 M	317 M	323 M
Hybrid Full CRL	206 M	406 M	664 M	783 M	859 M
DSRC With RSE No/Full CRL	0 M	135 M	178 M	178 M	178 M

4. Communication costs conclusions

Of the three scenarios considered, the DSRC with RSE ended up being the most economically viable as well as allowing for the most security. While cellular and hybrid show some merits, the costs and security concerns that they hold make them generally less attractive options for the CDDS. The implementation of a DSRC system, however, will take time. A 15 year phase-in plan has been assumed to be necessary for the RSEs, but other options may be considered. In addition, decisions on how to implement ideas such as an incrementally updating CRL must be further analyzed.

F. Security credentials management system cost modeling

Beyond the costs of the vehicle equipment and the fuel economy impact of that equipment (due to increased weight), we need to account for the costs of services that support the V2V system for the vehicle fleet. In addition to the cost of ensuring that the different elements of the V2V system are able to communicate, discussed above, another such cost is for the SCMS. The main function of the SCMS is to ensure that the communications from vehicles to other vehicles are authentic and can be trusted. Additional information on the SCMS is found in Section IX.

1. Preliminary projected costs for SCMS

In estimating the costs for the SCMS, we anticipate that a fee of approximately \$3.14 per vehicle could support the SCMS for all three scenarios. This fee would most likely be a one-time fee incorporated into the purchase price of a new vehicle or aftermarket equipment. The fee collected from the new vehicle or aftermarket sales each year would support the operations of the SCMS for that year. The operation of the SCMS in the next year would be supported by the fees collected from the new vehicle or aftermarket sales for that year.

We arrived at the conclusion that a fee of \$3.14 per new vehicle sold can support the SCMS by first estimating the costs of the SCMS for each year (beginning in 2020—our tentative first year for implementing the V2V system). This annual cost varies over time (with the first year being the least costly) because additional infrastructure is needed to support an increasing number of vehicles as V2V technology penetrates the fleet. We estimate the cost to support the SCMS ranges from \$5 to \$36 million in year 2020, whereas we estimate the cost to range from \$23 to \$93 million in year 2058. However, the currently available information indicates that the average *annual* cost for the SCMS over this span of 39 years (2020 to 2058) is \$60 million. We anticipate that this average annual cost could be covered by a \$3.14 fee collected along with the purchase of each new vehicle.

In order to understand the costs of the SCMS, we need to first define the components of the SCMS and how they interact with each other. The SCMS is made up of defined "components" that all have specified jobs and contribute to the operation of the SCMS function for V2V, including the components that make up the current system design to enable privacy while meeting system security needs. Details regarding the current system design and its components are found in Section IX.B.

a) Scenarios and assumptions used in developing preliminary projected costs

This analysis of costs is based on the latest SCMS design specifications (current as of January 2014) developed collaboratively with NHTSA and CAMP. These specifications establish parameters that the SCMS would likely need to meet in order to accomplish the aforementioned goals. It is important to note that these specifications are not finalized and could change. The following is a discussion of the assumptions that we are currently using for the purposes of estimating the potential costs of the SCMS.

(1) Technology Sales Scenario Assumptions

For the purposes of calculating the preliminary potential costs of the SCMS in this section, we will be using the same three technology implementation scenarios that we used to calculate Vehicle Equipment Costs, above. As a reminder, the three scenarios all based on a projected vehicle sale that starts at 17.04 million in 2020 and increase to 20.38 million in 2050. The sales stay flat at the 2050 level afterwards. These scenarios are briefly summarized as follows.

- Scenario 1: OBE on new vehicles with 35 percent-70 percent-100 percent phase-in starting in MY2020 with aftermarket devices
- Scenario 2: slower OBE implementation than that specified in Scenario 1, no aftermarket
- Scenario 3: the slowest OBE implementation among the three scenario and the rate would not reach the 100 percent level as did other two scenarios, no aftermarket

(2) Certificate issuance assumptions

For this analysis, we are assuming that a new vehicle will receive a three-year batch of reusable, overlapping five-minute certificates valid for one week.[340] The term "overlapping" in this context refers to the fact that any certificate can be used at any time during the validity period.[341] Key implications of this design are as follows:

- Certificates do not expire unless they are used, or the week ends. They are not time sensitive.
- Depending on the number of certificates designated for one week, they will be reused an uncertain number of times with no predetermined order.
- The certificate batch size may be 3,000, which is based on a set of approximately 20 certificates being used per week. Thus, the 3,000 certificate batch size would cover three years' of use before requiring certificate updates.
- There may be some discretion about how many certificates will be designated for a one-week period. This would be based on the choice of the user, OEMs, or SCMS owners/operators. However, the current assumption is 20 certificates per week.[342]

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[340] Security Credentials Management System (SCMS) Design and Analysis for the Connected Vehicle System (Booz Allen Hamilton, Inc., Dec. 2013, at 14). See Docket No. NHTSA-2014-0022
[341] Id.
[342] Id.

Afterwards, each vehicle will receive updates with two years of certificates at two year intervals.

We note that the variable that can cause the largest changes in overall cost is the frequency of certificate downloads. The final decision on this variable has not been made, and costs could change in the future based in large part on this variable.

(3) Hardware/software assumptions

Another important cost driver is the fact that hardware and software need to be refreshed every five years in order to keep the SCMS function equipped with the latest security capabilities. This assumption has been included in the cost estimates, which show an increase in costs every five years.[343]

(4) Location assumption

The estimates are based on Richland, WA, as the baseline for all functions, in order to be consistent with the BAH cost model.[344] BAH identified cost factors for Richland, WA, as well as Denver, CO; Chicago, IL; San Antonio, TX; Washington, DC; and Gastonia, NC. Richland was chosen as a baseline given the spread of costs for the area and used to produce an initial calculation of cost for the purpose of the SCMS cost analysis.

b) Annual total preliminary cost for the SCMS

In order to estimate the cost per new vehicle sold, we first need to estimate the cost of the entire SCMS. This cost is different for each year because the number of vehicles operating with V2V capabilities will increase over time. When the number of these vehicles increases, the SCMS will need to support the functions of the additional vehicles with an increased capacity to be able to generate and issue security certificates. Table XI-26, below, shows the likely cost needed to support each SCMS function. Each column (labeled 0, 10, 20, 30, 40) show the costs for the SCMS function in that year. For example, the PCA will cost $5,541,402 in Year 0 to operate. However, that same function will cost $7,196,135 to operate in Year 10. The last row in Table XI-26 shows the total cost of the entire SCMS in each of those years. All of these costs are undiscounted. The costs in Table XI-26 also assume that vehicles are being sold at the rate described in "Technology Sales Scenario 1." In other words, we are assuming an increasing sales volume (beginning at 17 million in 2020, and rising to approximately 20 million thereafter starting in 2050).

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[343] Id., at 106.
[344] Id.

Table XI-26 Undiscounted Cost Estimates per Component for Selected Years, Scenario 1, Two Year Downloads

Component	Year				
	0	10	20	30	40
PCA	$5,541,402	$7,196,135	$11,948,687	$16,281,686	$20,257,673
RA	$6,671,907	$7,755,342	$13,636,463	$19,206,293	$24,471,619
LA	$4,918,141	$5,644,934	$9,964,652	$14,117,090	$18,048,462
MA	$3,546,999	$3,757,398	$5,514,098	$7,256,497	$8,815,887
LOP	$1,320,948	$1,829,286	$3,434,603	$5,201,161	$6,214,164
ECA	$4,079,230	$4,167,392	$4,167,392	$4,167,392	$4,167,392
Intermediate CA	$4,184,493	$4,024,319	$7,940,176	$11,856,033	$15,689,120
Root CA	$1,609,923	$1,592,732	$1,592,732	$1,592,732	$1,592,732
DCM	$4,061,098	$4,507,122	$4,507,122	$4,507,122	$4,507,122
SCMS Manager	$323,330	$679,564	$679,564	$679,564	$679,564
Total Cost	$36,257,471	$41,154,224	$63,385,488	$84,865,570	$104,443,733

The preliminary costs are generally driven by new hardware, software, facilities, and full time equivalent positions (FTEs). However, the costs do not rise in a linear fashion because new hardware and software is necessary at regular intervals (i.e., every 4 to 5 years). Thus, the costs in the first year and in every fifth year are noticeably higher in the estimates than in other years as a result. In these years, the total costs increase by a fairly significant margin but then decrease again in the next year. However, when we average the costs of the entire SCMS over this 40-year period, the estimated annual cost based on preliminary information for the SCMS is $59 million.

We note that the cost estimates above are subject to change given the uncertainty surrounding the functions of various aspects of the SCMS. The most notable uncertainty is the Misbehavior Authority (MA). As described above, this function is responsible for detecting misbehavior (i.e., systems that are not broadcasting accurate information) and publishing CRLs to notify other participants in the V2V environment that they should not trust the information from those sources. At this point, it is unclear how the SCMS will perform this function. Thus, it is unclear whether the cost estimates for this function are accurate. At the moment, we have based it on estimations of hardware, software, facilities, and employee needs according to current specifications. We intend to update our cost estimates for this function (as well as others) as the details of those functions become more definite in the future.

c) Cost methodology for component functions of the SCMS

In order to arrive at the annual and total preliminary cost estimates for the entire SCMS, we had to examine the costs for each component function of the SCMS. While this report does not present the calculations for each component function, we have selected an illustrative example to communicate the methodology that we used to arrive at the estimates for each component. Table XI-27 below shows the annual cost for the Pseudonym Certificate Authority (PCA) function in each of five different years (2020, 2030, 2040, 2050, and 2060). Table XI-27 also shows the different types of expenditures needed to support the PCA and how each is anticipated to change over time.

Table XI-27 Undiscounted Cost Estimate of PCA for Selected Years, Scenario 1, Two Year Downloads

PCA	Year				
Cost Category	**0**	**10**	**20**	**30**	**40**
Hardware Purchase	$615,472	$1,500,762	$1,968,620	$2,141,499	$2,203,241
Hardware, O&M	$0	$107,850	$179,301	$206,833	$220,324
Software Purchase	$2,311	$7,801	$10,729	$12,642	$12,854
Software, O&M	$0	$905	$1,585	$1,993	$2,314
Facilities: Initial Cost	$1,037,695	$1,620,582	$1,894,360	$2,115,775	$2,115,775
Facilities: Annual	$0	$72,310	$122,241	$145,169	$159,464
FTEs: Total Costs	$3,885,925	$3,885,925	$7,771,850	$11,657,775	$15,543,700
Total Cost	$5,541,402	$7,196,135	$11,948,687	$16,281,686	$20,257,673

2. Funding the SCMS

For such a system, there must be a cost to the user. In the case of the SCMS function, we assume that the user will have to pay a cost for their use of the SCMS system upfront, when a new vehicle is purchased (i.e., the cost of the SCMS becomes part of the new vehicle purchase price). While other payment methods are possible, it seems that including the cost of the SCMS in the price of the new vehicle or the price of aftermarket devices is the easiest way to ensure payment for (and continued participation in) the system. Other payment methods (e.g., monthly fees) may discourage users from participating in the V2V environment. If this happens, the number of on-the-road vehicles that are communicating will be reduced, and the effectiveness of the V2V system will consequently decrease. The agency emphasizes, however, that it will consider this issue further going forward as new information becomes available.

G. Conclusion of preliminary V2V implementation cost estimates

When considering all four parts of this preliminary cost analysis (vehicle equipment, fuel economy impact, SCMS, and communications costs), we estimate that the total costs to the consumer for each new vehicle will be approximately $341 - $350 (across the 3 percent to 7 percent discount rates) in 2020. We note that over time this amount will decrease to approximately $209 - $235 in 2058 (when considering the discount rates and the three sales scenarios), due in large part to cost reductions that manufacturers will realize as they gain more experience manufacturing V2V vehicle equipment (learning). We note the total costs will decrease over time even though certain costs will increase over time. While the SCMS costs will increase over time due to the need to support an increasing number of vehicles, these costs are small in comparison to the vehicle equipment costs. Thus, the effect of manufacturer learning in reducing the costs over time substantially outweighs cost increases such as the SCMS.

Preliminary costs are summarized mainly on a model year basis. For new vehicle sales, costs for the V2V system occur when the vehicle is sold. For fuel economy impacts, costs are discounted back to present value - when the vehicle is sold. For SCMS and communication costs, costs are assumed to be charged when the vehicle is sold to cover these costs that would occur in the same calendar year as the model year when it is sold. Thus, the assumption is that at the time the vehicle is sold, the price of the vehicle is increased to pay for what is needed in that year. The estimated costs per vehicle for the SCMS (ranging from $1 to $6 per vehicle) and communications (ranging from $3 to $13 per vehicle) are relatively low.

For aftermarket sales, costs occur when the aftermarket equipment is sold, which is not the same as the model year of the vehicle for which it has been purchased. Thus, the calendar year of the assumed sale is when aftermarket costs are added to the model year sales to get total costs for the model year. Here again, costs for SCMS and communication could be charged at the point of sale.

Because of the large number of variables affecting the costs of the V2V system, the preliminary total annual costs of the system fluctuates substantially from year to year. The total costs for new vehicles (over three sales scenarios and two discount rates) rise from $0.3 to $2.1 billion dollars in 2020 to $1.1 to $6.4 billion in 2022, before decreasing slowly to a relatively stable level of $1.1 to $4.6 billion.

To put the costs into perspective, we compared the passenger car costs over time in the four cost categories, using the 3 percent discount rate. The OEM costs are 95 percent of total costs initially, then decreasing slowly to 88 percent of total costs as the learning curve takes effect and other costs increase. The fuel costs (at around 5 percent) are typically higher than the communication costs (at around 4 percent) and the SCMS cost stay in the 1 to 2 percent range over the years.

H. Economic practicability

Under the Safety Act, standards set by NHTSA must be practicable. One criteria of a practicable standard is that it is economically feasible (i.e., compliance with the standard is not so burdensome [costly] so as to create a significant harm to a well-established industry). If a standard is deemed to be economically infeasible, it can be considered impracticable by a court. Therefore, the economic feasibility of V2V will need to be considered when deciding whether to mandate V2V. Our analysis is based on the information on potential costs for a V2V system that has been collected so far by the agency, even while recognizing that the information is preliminary and that additional information will come to light as the agency moves forward.

Although no V2V system currently exits other than in prototype form, we have attempted to make a preliminary estimate of costs to implement such a system based on available prototypes and projections about system deployment. Based on those costs, it appears likely that any standards to require elements of the V2V system will be economically practicable. We emphasize that these estimates are subject to substantial amendment as more information is acquired and any plan for implementation gains greater clarity. NHTSA and DOT will be constantly attentive to options that may reduce these costs. More important, these projected costs are best thought of as the price for a new and important element of the nation's transportation infrastructure and should be considered jointly with the safety and other benefits the system would bring as discussed in the next section.

XII. Preliminary Effectiveness and Benefits Estimates of V2V

A. Analysis of preliminary benefits of V2V technology

The agency estimates the system crash avoidance and crashworthiness effectiveness by comparing crash rates and the injury probabilities of vehicles with and without V2V technology. The agency focused its evaluation on IMA and LTA, the two applications currently considered to be exclusively enabled by V2V technology. To correspond with the cost estimates, benefits were also estimated for the three technology implementation scenarios described in the cost section.

Based on the estimation methodologies described in this section, the agency estimates that IMA would help drivers avoid 41 to 55 percent of target intersection crashes[345] and reduce the severity of intersection crashes by an average of 1.17 mph delta-V.

The agency estimates that LTA would prevent 36 to 62 percent of left turn crashes. LTA is considered to have no impact on mitigating the severity of the left turn crashes that cannot be avoided. Therefore, the crashworthiness effectiveness for LTA is assumed to be zero in this analysis.

We therefore estimate that IMA and LTA together would prevent a maximum of 413,000 to 592,000 crashes, save 777 to 1,083 lives, and reduce 191,000 to 270,000 MAIS injuries under the fast technology implementation plan specified in Scenario 1.

Under Scenario 2, a slower implementation pace than Scenario 1, IMA and LTA would also accrue the maximum benefits as in Scenario 1. The primary difference between these two scenarios is that Scenario 1 would achieve other levels of benefits (e.g., 70 or 90 percent of the maximum benefit) 2 to 3 years earlier than would Scenario 2.

Under Scenario 3, the slowest implementation pace among the three, which only reaches 25 percent of the full implementation level, IMA and LTA would accrue at most 6 percent of the maximum benefits achieved by Scenarios 1 and 2. The disparity in benefits demonstrates that in order to realize the full potential of V2V technology, achieving full implementation over time is critical.

1. Analysis overview

Preliminary cost and benefit estimates vary with the V2V safety device implementation strategy. As stated in the cost section, the agency used three scenarios to examine the variation of

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[345] The result of adding 15 – 24 percent for PCP-S and 26 - 31 percent for PCP-M.

the cost and benefit estimates and to understand the impact of various technology implementation schedules on the costs and benefits. The first scenario represents the most aggressive V2V implementation scenario among the three, while the third one represents the slowest and lowest implementation schedule among the three. The detailed description of these implementation scenarios are provided above in Section XI.

As stated earlier, the preliminary benefit estimates are for IMA and LTA only. The agency intends to examine the benefits of other safety applications -- FCW, BSW/LCW, and DNPW – when sufficient data are available to estimate their effectiveness.

The preliminary benefit estimates presented in this report include (1) the maximum undiscounted annual benefits (in terms of fatalities and injuries reduced and crashes avoided) when all passenger vehicles can communicate with each other, and (2) the undiscounted annual benefits for calendar years 2020 to 2058.

The benefits of a V2V safety application depend upon three primary components:

- The target population that would be impacted by the application,
- The system effectiveness of the application in preventing the crash (crash avoidance) and/or mitigating the severity of the crash (crashworthiness), and
- The probability that involved vehicles can communicate with each other (communication probability).

Of these three components, communication probability would vary with the number of V2V-equipped vehicles entering into the market each year. Therefore, at a given year *i* of a V2V implementation, the benefits of an application can be noted as:

Equation XII-1 Benefits Estimation Calculation

$$B_i = TP * E_a * C_i + TP * (1 - E_a) * E_w * C_i$$

Where, B_i = the benefit for year *i*

TP = the target population

E_a = the crash avoidance effectiveness of an application

E_w = the crashworthiness effectiveness of an application

C_i = the communication rate.

The target population (TP) includes crashes, fatalities, injuries, and property damaged only vehicles (PDOV, vehicles that only incur property damage and none of their occupants incur an injury). Effectiveness (E_a and E_w) of a safety system is derived by comparing crash rates and injury rates for vehicle with and without the system. The effectiveness can be represented by the generalized formula:

Equation XII-2 Effectiveness Calculation

$$E = 1 - \frac{P_{with}}{P_{without}}$$

Where, P_{with} = crash rate (or injury rate for crashworthiness) for vehicle with the system

$P_{without}$ = crash rate (or injury rate for crashworthiness) for vehicles without the system.

For crash avoidance, the effectiveness (E_a) takes into account both the reduction in exposure to conflict and the probability of a crash when a conflict occurs.

The communication rate (C_i) is the probability that two passenger vehicles can communicate with each other, which means that it depends on the number of vehicles that have V2V, and is consequently different depending on the technology implementation scenarios. Besides C_i, the benefit process represented by Equation XII-1 is identical for all implementation scenarios; meaning the other variables in the equation remain the same (e.g., the target population). The next sections discuss in greater detail the implementation scenarios and the three primary factors in determining benefits: target population, and effectiveness, and communication rates.

2. Technology implementation scenarios

Restated here for convenience, following is a basic summary of the three potential technology deployment scenarios used for the cost and benefits analysis in this report. Additional information on these scenarios is found in Section XI.C.3.a). As previously noted, the dates selected here are simply assumptions made for the convenience of this analysis, and reflect no judgment by the agency on timing or phase-in requirements.

a) Scenario 1

- 35 percent-70 percent-100 percent vehicle equipment phase-in starting in MY2020
- 100 percent installation of two safety applications for those with vehicle equipment
- Aftermarket deployment for MY2015-2021 vehicles (applicable vehicles)
    - Starting 2022 and continuing for a total of 5 years
    - 5 percent of applicable vehicles for 2022 and 2023
        - For example, for year 2022, applicable old vehicles include the survived MY2015-2019 vehicles, 65 percent of the survived MY2020 vehicles, and 30 percent of the survived MY2021 vehicles. Five percent of these vehicles would be equipped with an aftermarket device.

        - For year 2023, the applicable old vehicles include 95 percent of those applicable old vehicles that were defined for year 2022 and would survive in year 2023.
    - 10 percent of applicable vehicles for 2024-2026
    - The estimated number of aftermarket sales for the 5 implementation years in this scenario are:
        - 4.70 million in MY2022
        - 4.37 million in MY2023
        - 8.09 million in MY2024
        - 7.06 million in MY2025
        - 6.11 million in MY2026
- ASD and VAD are assumed to have an equal penetration rate each year.

b) Scenario 2

- 35 percent-70 percent-100 percent vehicle equipment phase-in starting in MY2020
- 50 percent installation of two safety applications for MY2020-2022 vehicles that have vehicle equipment, 60 percent for MY2023, 70 percent for MY2024, 80 percent for MY2025, 90 percent for MY2026, 100 percent for MY2027 and later.
- No Aftermarket deployment

c) Scenario 3

- 5 percent vehicle equipment for MY2020, 15 percent for MY2021, 25 percent for MY2022 and newer vehicles
- 100 percent installation of two safety applications for those vehicles that have vehicle equipment
- No Aftermarket deployment

3. Target population for V2V technology

The target population includes crashes, fatalities, injuries, and property-damage-only vehicles (PDOV) that are vehicles that only incur property damage and none of their occupants incur an injury. Although the preliminary benefit estimate is only for the IMA and LTA safety applications, the target population for FCW and LCW and for heavy vehicles is also provided here to offer a comprehensive illustration of the potential safety impact that could result from the V2V-based safety applications.

Overall, the agency used an average of 2010 and 2011 CDS and FARS data to determine that there are approximately 5.37 million police-reported crashes annually in the United States[346] involving approximately 32,683 fatalities and 4.29 million MAIS[347,348] 1-5 injuries. Of these crashes, 3.34 million crashes involving two or three passenger vehicles[349] would be impacted by the V2V-based safety applications. These crashes account for 62.3 percent of the total crashes.

Crashes *not* included in the 3.34 million are (a) 1.5 million single-vehicle crashes and 230,000 crashes that involved motorcycles, since these crashes are not expected to be benefited by V2V-based safety applications, (b) about 60,000 crashes where four or more vehicles were involved as they could involve more complicated and less clear interactions between vehicles and require further evaluation, and (3) about 240,000 crashes where heavy vehicles[350] were involved, because the agency is only evaluating passenger vehicle[351] crashes at this time and plans to address crashes involving heavy vehicles in a later decision. However, the V2V-based applications would affect 3.59 million crashes (66.9% of the total crashes) if heavy-vehicle crashes were included.[352]

To identify the target crash population for a specific V2V-based application, the agency starts with the 37 pre-crash scenarios as described in Section III.A. The target population for an application is categorized into major scenarios where the application might perform differently. The following describes the major scenarios for intersection crashes (affected by IMA and LTA), rear-end crashes (FCW), and lane change/merge crashes (BSW/LCW).

- Intersection crashes for IMA and LTA
    - turn-into path into same direction or opposite direction (i.e., "turn-into path, initial opposite direction" crashes are crashes where one involved vehicle is making a left turn at the intersection and the other vehicle is traveling straight through the intersection from the opposite direction)

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[346] Based on 2010-2011 NASS-GES and FARS data.
[347] MAIS (Maximum Abbreviated Injury Scale) represents the maximum injury severity of an occupant at an Abbreviated Injury Scale (AIS) level. AIS ranks individual injuries by body region on a scale of 1 to 6: 1=minor, 2=moderate, 3=serious, 4=severe, 5=critical, and 6=maximum (untreatable).
[348] GES and FARS only record the police-reported crash severity scale known as KABCO: K = fatal injury, A = incapacitating injury, B = non-incapacitating injury, C = possible injury, O = no injury. These KABCO injuries the n were converted to MAIS scale through a KABCO-MAIS translator. The KABCO-MAIS translator was established using 1982-1986 NASS (old NASS) and 2000-2007 Crashworthiness Data System (CDS). Old NASS and CDS recorded both KABCO and MAIS scales thus enabling us to create the KABCO-translator.
[349] Passenger-vehicle-to-passenger-vehicle and passenger-vehicle-to-heavy-vehicle account for 4.5 percent (241,000).
[350] Heavy vehicles include trucks and buses with GVWR greater than 10,000 pounds.
[351] Passenger vehicles include passenger cars, vans, minivans, sport utility vehicles, and light pickup trucks with gross vehicle weight rating (GVWR) 10,000 pounds or less.
[352] Passenger-vehicle-to-passenger-vehicle and passenger-vehicle-to-heavy-vehicle account for 4.5 percent (241,000).

  - straight cross passing
- Rear-end crashes for FCW
  - Lead vehicle stopped (LVS)
  - Lead vehicle moving at a slower speed or was accelerating (LVM)
  - Lead vehicle decelerating (LVD)
- Lane change/merge crashes for BSW/LCW have been defined as crashes where a vehicle made a lane changing/merging maneuver prior to the crash

Note that "intersection" in this analysis included intersection, intersection-related, driveway/alley, and driveway access areas. Rear-end crashes does not include crashes where the lead vehicle made a lane change/merge pre-crash maneuver. Furthermore, crashes involving alcohol, vehicle failure, and loss-of-control are also excluded, because we assumed that V2V-based safety applications would not produce an effective response by the driver under these conditions.[353] For the preliminary benefit analysis, the agency focused only on IMA and LTA. FCW was not included in the benefits estimation because of the significant overlap with radar-based FCW systems; BSW/LCW and DNPW were also not included because insufficient data exists at this time to assess their effectiveness.

Table XII-1 shows crash statistics for the four safety applications. As shown, annually there are 2.94 million crashes with 2,669 fatalities and 1.07 million MAIS 1-5 injuries that could be addressed by these four V2V safety applications. In addition, about 4.05 million PDOV crashes could also be addressed. Of these, 1.04 million crashes, 1,932 fatalities, 450,000 MAIS 1-5 injuries, and 1.28 million PDOVs could be impacted by IMA and LTA. Separately, IMA could impact 760,000intersection crashes and thus the 1,637 associated fatalities and 300,000MAIS 1-5 injuries. LTA could impact 280,000 crashes and the associated 295 fatalities and 150,000 MAIS 1-5 injuries.

[353] Crash scenarios were excluded based on the criteria that an impaired driver would be required to react, and the fact of their impairment would likely lead them not to react as required.

Table XII-1 Safety Target Population for FCW, LCW, IMA, and LTA - Passenger Vehicles[354]

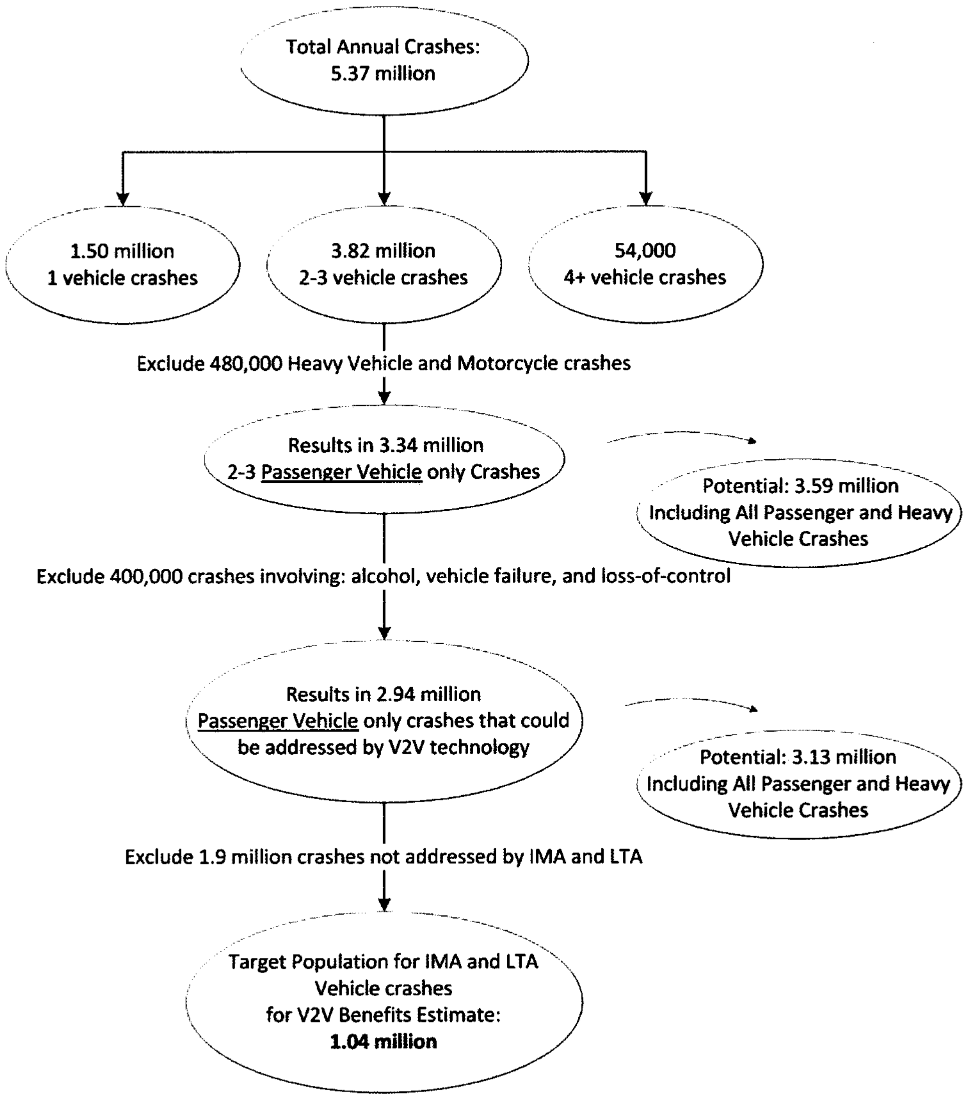
	FCW (LVS)	FCW (LVM)	FCW (LVD)	FCW TOTAL	IMA	LTA	IMA, & LTA TOTAL	LCW	GRAND TOTAL
Crashes	946,668	167,807	329,510	1,443,985	757,195	283,503	1,040,698	458,506	2,943,189
PDOC[355]	641,153	113,407	225,797	980,357	472,694	150,530	623,224	362,688	1,966,269
Injury	305,515	54,400	103,713	463,628	284,501	132,973	417,474	95,818	976,920
Fatality	161	234	47	442	1,637	295	1,932	295	2,669
MAIS 1-5 Injuries	342,516	63,350	117,425	523,291	303,987	150,674	454,661	94,430	1,072,382
PDOVs[1] in PDOC	1,321,417	233,732	465,367	2,020,516	974,223	310,242	1,284,465	747,500	4,052,481

Figure XII-1 provides a graphical breakdown of crashes and the process as discussed previously for deriving the target population for benefits estimation. The potential target population as shown is where heavy vehicle crashes are considered. The graphical breakdown begins with the total annual number of police-reported crashes of 5.37 million, and ends with the target crashes of 1.04 million for IMA and LTA.

[354] Source: 2010-2011 GES and FARS.

[355] Property-damage-only crash.

Figure XII-1 V2V Benefits Estimation Target Population (Annual) Breakdown



B. Effectiveness of the V2V safety applications

The system crash avoidance and crashworthiness effectiveness is determined by comparing crash rates and the injury probabilities of vehicles with and without V2V. Since V2V is an emerging technology and is not in production, a statistical analysis of vehicles with and without the technology using real-world crash data was not feasible. Instead, the agency developed a computer simulation model, Safety Impact Methodology (SIM),[356] and a laboratory driver simulator (MiniSim), to estimate the effectiveness and then the preliminary benefits of V2V-based safety application technologies, specifically, IMA and LTA.[357] Therefore, these two sources are the basis for estimating the crash avoidance and crashworthiness values.

1. Safety Impact Methodology - SIM

In order to obtain a crash warning using V2V technology, two V2V-equipped vehicles need to interact during a potential crash situation – if a V2V-equipped vehicle interacts with a non-V2V-equipped vehicle in a potential crash situation, no warning is to be expected, because the non-equipped vehicle would produce no BSM for the equipped vehicle to recognize and respond to. To be able to estimate the effectiveness of advanced crash avoidance technology such as V2V, NHTSA developed a methodology that uses available data and computer simulation,[358] extending current estimation capabilities and enabling V2V technology to be "exposed" to more conflict situations to make up for the lack of crashes in the real-world crash databases. This allows the agency to better comprehend the crash avoidance potential and the performance criteria of the V2V technology prior to the technology's actual deployment.

The "Safety Impact Methodology" or "SIM" estimates safety benefits in terms of the number of crashes avoided using the estimated effectiveness of the safety applications to avoid crashes. These estimates are obtained using the following set of equations:

Equation XII-3 Number of Crashes Avoided Calculation

$$\textit{Number of Crashes Avoided} = \text{Number of Target Crashes} \times \text{Application Effectiveness}$$

The application effectiveness is estimated based on the following equation:

Equation XII-4 Application Effectiveness Calculation

$$\textit{Application Effectiveness} = 1 - \text{Exposure Ratio} \times \text{Crash Prevention Ratio}$$

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[356] Safety Impact Methodology (SIM): Application and Results of the Advanced Crash Avoidance Technologies (ACAT) Program (Funke, Srinivasan, Ranganathan, and Burgett, June 2011, Paper Number 11-0367, 22nd International Technical Conference on the Enhanced Safety of Vehicles). See www-nrd.nhtsa.dot.gov/pdf/esv/esv22/22ESV-000367.pdf (last accessed Jan. 29, 2014).

[357] The agency examined 50 intersection or left turn across path crashes from the NASS data base for which we had EDR information from both vehicles involved. Thus, we knew the velocity and brake activation of both vehicles from 5 seconds to 1 second before the crash. These analyses were used to determine that the SIM results did match very well with real crashes.

[358] For an overview of this methodology, see supra note 354.